Idaho National Laboratory

Technical Memorandum

To:

Title: Supply System Costs of Slash, Forest Thinnings, and Commercial Energy Wood Crops

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Platform: Feedstock

Date: September 2008

Number: TM2008-008-0 (INL/MIS-09-15228)

Purpose: The purpose of this Tech Memo is to assess supply system costs associated with using current state of technology to collect woody biomass residues (slash). In addition, supply system costs for forest thinnings and plantation energy wood crops are assessed to show variability based on feedstock. Minimizing woody biomass feedstock costs to the biorefinery (which includes all logistics costs associated with harvest, handling, transport, and preprocessing) is necessary to develop a sustainable cellulosic ethanol industry and to help achieve U.S. energy independence. This report builds on a joint ORNL-INL 2007 report titled "A Preliminary Assessment of the State of Harvest and Collection Technology for Forest Residues"(Wilkerson et al. 2008). The preliminary assessment outlined the availability of US forest resources and described current technologies used for harvesting, transporting, storing, and preprocessing woody biomass. County level maps were presented in the report that showed the spatial availability of logging residues and fuel treatment thinnings. The information in this Tech Memo estimates the current costs associated with these residue collection technologies and includes forest thinnings and wood grown as an energy crop. Using a combination of values obtained from journals, published models, and unpublished INL data, a delivered cost of $20.50 per bone dry ton (bdt) was calculated to deliver comminuted slash to the throat of the bioreactor. Costs to deliver forest thinnings are calculated as $51.85/bdt. Logistics costs for plantation energy wood harvested with conventional logging technologies and a specialized willow harvester were about $30.52/bdt and $34.63/bdt. These data represent current costs that can be used to measure improvements of unit operations in the harvest, collection, transportation, and storage systems and can be used to help identify improvements to reduce the delivered cost of biomass.

Supply System Costs of Slash, Forest Thinnings, and Commercial Energy Wood Crops

INTRODUCTION

Nearly one-third of the feedstocks for lignocellulosic transportation fuel production identified in the Billion Ton Study come from woody sources (Perlack 2005). It has been estimated that 368 million dry tons can be produced annually in the United States from logging residues and fuel treatment thinnings. Currently, very little of this woody biomass is used for energy production due to the costs and difficulty in collecting and transporting this material (Rummer 2003). However, minimizing woody biomass feedstock costs to the biorefinery (which includes all logistics costs associated with harvesting, handling, transporting, and preprocessing) is necessary to develop a sustainable cellulosic ethanol industry. Because of growing interest in using woody biomass resources to help achieve U.S. energy independence, studies have investigated costs associated with the harvest and collection of slash from commercial timber harvests, residue from forest thinnings, and plantation energy wood.

In commercial timber harvests, 20–30% of the total volume of woody biomass is left behind as residue. This material, known as "slash," consists mostly of tree tops and limbs cut from timber destined for lumber production or as pulp wood. Currently, spot markets exist for this slash as feed for wood or co-fired boilers; however, the majority of this material is piled and burned in the forest (Pierovich 1973; Rawlings et al. 2004). The recovery of slash within the parameters stated in this memo is the state of technology being reported. Estimates are also included for two other potentially important sources of woody biomass – thinnings and short-rotation energy plantations.

Forest thinning operations are another source of woody residue as woody biomass is removed to improve overall forest health—to increase the growth of the most valuable trees, or to reduce the risk of catastrophic fire (Rummer 2003). In the Western United States, fire suppression thinnings represent a large volume of biomass that could potentially be used for biofuels production. However, these materials are generally costly to harvest and collect because, unlike the tops and limbs associated with whole-tree harvest for commercial roundwood products (sawlogs, pulpwood, etc.), the incremental cost of the biomass includes all the stump-to-facility activities rather than only the roadside-to-facility operations. (Offset is one way to pay for thinning, but should not be considered a part of the cost or benefit of the biomass.)

As the cellulosic ethanol industry matures, plantations producing energy wood could become a major source of woody biomass (Perlack 2005). An estimated 340,000 acres of plantation-grown trees are currently growing in the U.S.(Walsh 2008) and are potentially available for bioenergy. Hybrid poplar, willow, and sycamore are currently being grown in different areas of the country to assess the economics of farming these trees for bioenergy. Some of these plantations were planted for pulp production, but due to economic constraints in the pulp and paper industry, growers are looking to the biofuels industry as a potential market. Moreover, the biomass production from these stands, potential for carbon sequestration, and consistency of the product make them attractive energy crops (Tharakan et al. 2003) (Yemshanov 2007).

HARVEST, COLLECTION, and TRANSPORTATION COST METHODOLOGY

Commercial Timber Harvest Slash

The logistics of commercial timber harvest are affected by many variables, such as terrain, soil type, timber species, tree diameter, etc. This has resulted in literally dozens of timber harvest techniques, ranging from skidding with horses to helicopter logging. One of the most common and cost-effective timber harvest operations uses a feller/buncher, grapple skidder, and an excavator equipped with a dangle-head processor (Figure 1).

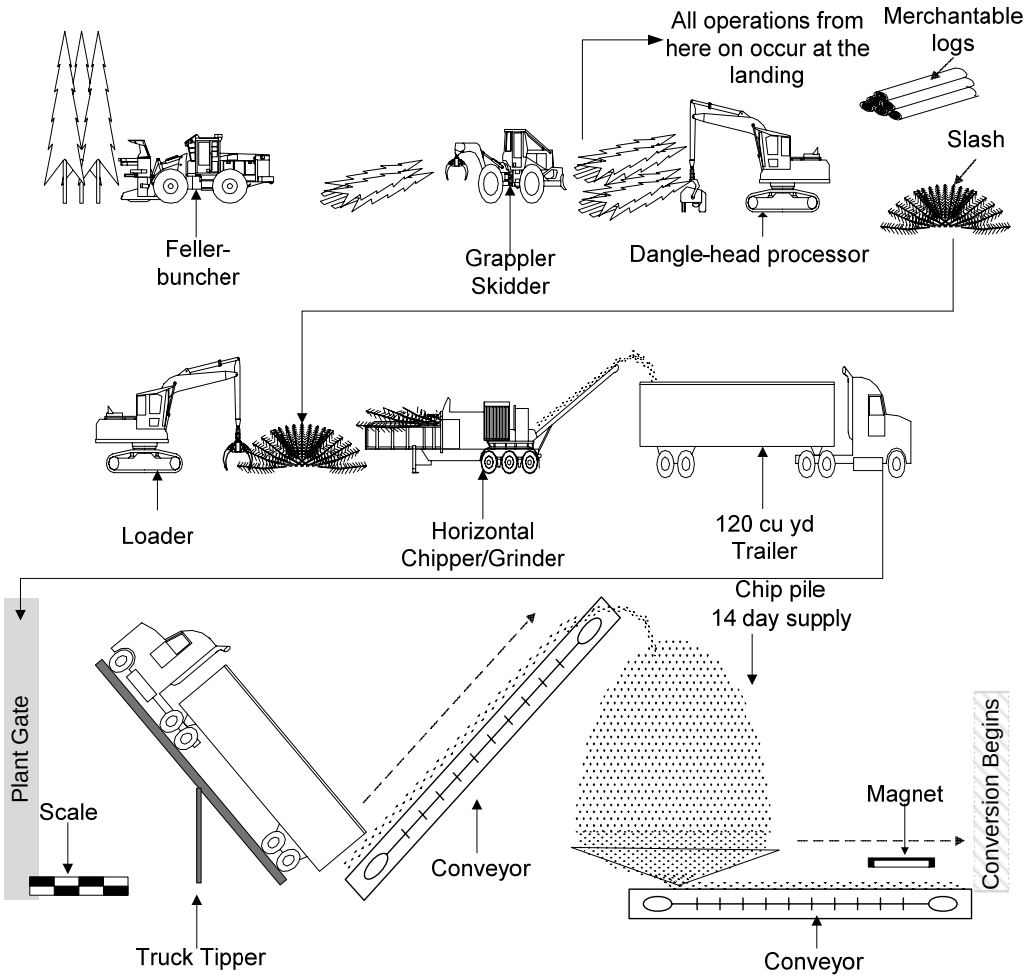

Figure 1. Common timber harvest operation with slash grinding and woody biomass receiving and storing system.

The emphasis of this system is recovery of merchantable timber, and the slash removed is left onsite. Therefore, the biomass feedstock costs associated with slash recovery begin at the landing with grinding and loading into chip vans or wagons. Currently, there is no harvest cost associated with slash since harvesting was done during the collection of the merchantable timber. To achieve the most economical system of slash recovery, the landing needs to be accessible to large chip vans (Hartsough et al. 1995). Idaho National Laboratory (INL) has completed some

preliminary economic modeling of this scenario. In the modeling, the distance to transport the biomass was set at 50 miles, giving the conversion facility a 100-mile radius to obtain biomass. While 50 miles is a distance thought to be economically feasible (EIA 1998), the economic limit will depend strongly on transportation fuel costs and energy markets in the harvest area. FoRTS, the Forest Residues Trucking Simulator v.5, is an Excel-based calculator that helps identify cost-effective methods of transporting biomass from the forest to an end user. Figure 2 shows an example input page from the model. The program is available at http://www.srs.fs.usda.gov/forestops/biomass.htm. FoRTS has the following capabilities:

- Estimates loading and hauling costs for different combinations of equipment
- Evaluates the best mix (numbers and types) of equipment
- Compares different hauling routes
- Examines reloading, or two-stage, hauling opportunities

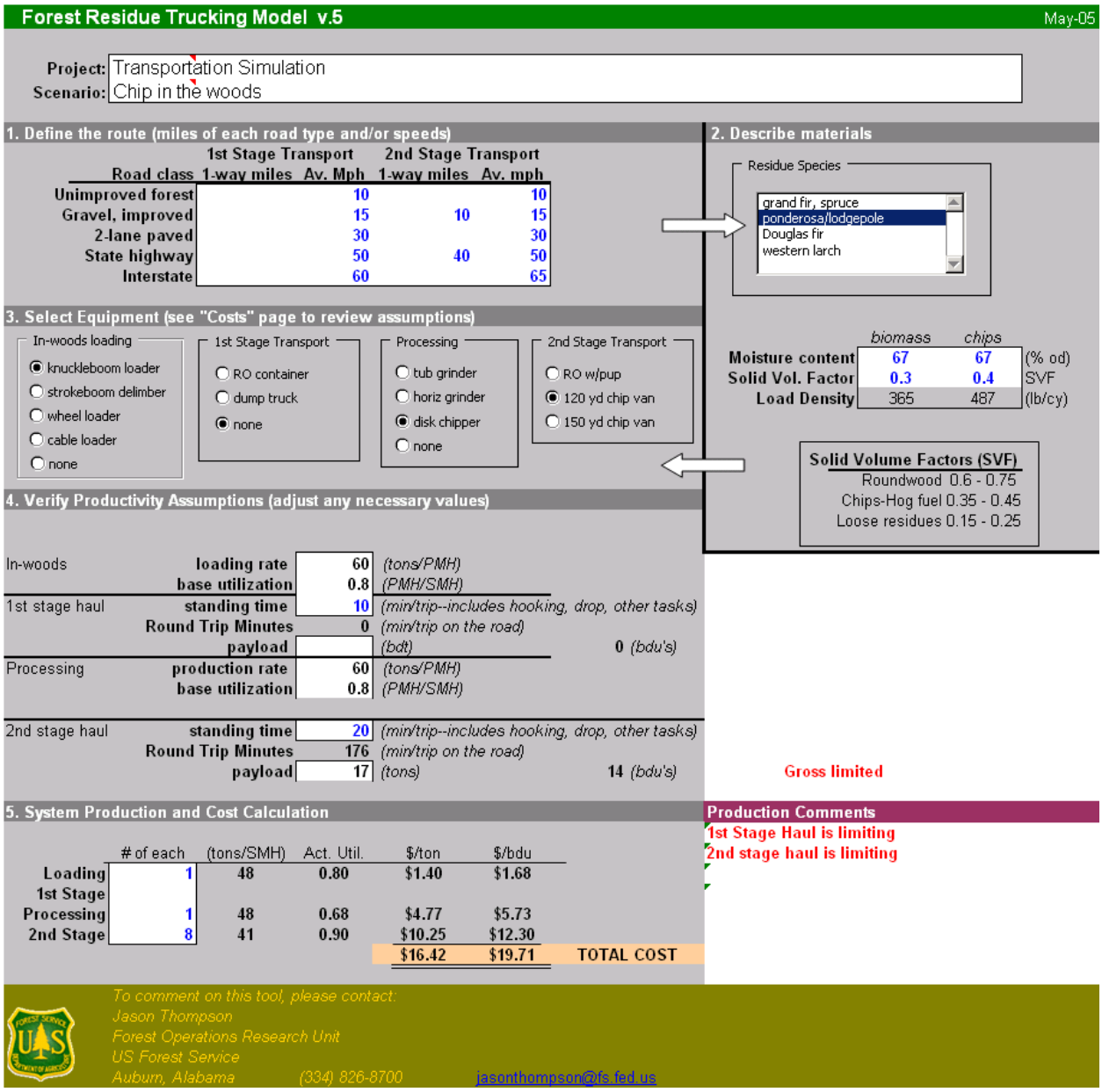

Figure 2. Inputs to FoRTS, the Forest Residues Trucking Simulator for slash and forest thinnings.

Using the FoRTS model and the following assumptions (knuckleboom loader, horizontal grinder, and hauling in 120 cu yd chip van), $per bone dry ton is obtained. Machine costs used to calculate $/bdt are reported in Appendix A, Table A-1. This cost is converted from 2005 dollars to 2007 dollars by using the conversion factor in Appendix A, Table A-2. Figure 2 shows the cost breakdown in 2005 dollars by cost input. Table 1 shows costs associated with each unit operation for removing the biomass and transporting it to the conversion facility. Table 2 shows the receiving and storage costs for each unit of operation of the system depicted in Figure 1. The receiving and storage system starts with scales to determine the weight of material arriving. The biomass is unloaded with a whole truck tipper and the material is dumped on to a conveyor. The conveyor deposits the chips into the queuing pile. A reclaimer is used to remove chips from the

pile and deliver them to the start of the conversion process. Wood chips are prone to self-heating and dry matter loss when moisture content is greater than about 20% (wet basis) (Springer 1979). To mitigate this potential problem, a just-in-time delivery system is used so that chips are seldom stored longer than 15 days and the pile height is held under 30 ft (Springer 1979; McDonald and Twaddle 2000). Receiving and storage costs were obtained from INL unpublished data. These costs are the same for each of the scenarios discussed in this report.

Table 1. FoRTS model unit operation costs.

Slash Harvest, Collection, and Transportation Costs in $/bdt							
Feller-buncher	Skidder	Processor	Loader	Chipper	120 cu yd Chip Van	Total 2005 $	Total 2007 $
n/a	n/a	n/a	$1.40	$4.77	$10.25	16.42	17.75

Table 2. Costs incurred at the receiving facility.

Receiving and Storage Costs in 2007 $/bdt						
Scale	Truck Tipper	Conveyor/ Reclaimer	Storage	Magnet	Subtotal	Stump-to-reactor cost
$0.21	$0.65	$1.32	$.50	$0.07	**$2.75**	**$17.75+$2.75 = $20.50**

The total cost per bdt for this system from stump to throat of the reactor is projected to be around $20/bdt (will be higher with standard van payload). The above supply system design for slash is the state-of-technology design that will be used as a comparison for future analyses of woody feedstock supply systems. There are many other systems currently being used, but this is being presented as the baseline system for the state-of-technology woody supply system. All other designs will be considered variations of this baseline. Two other systems are discussed below to highlight some significant differences in their feedstock compositions and collection systems.

Forest Thinnings and Plantation Energy Wood

Forest Thinnings

In the western United States, forest thinning is often performed for fire suppression purposes (Rummer 2003). In the eastern United States, forests may be thinned to improve forest health, cull undesirable species, and to improve production of high-value sawtimber. Materials from thinnings are often non-merchantable and the majority of these materials are stacked and burned. In order to obtain the volume of woody biomass identified in the Billion Ton Study (Perlack 2005), much of this material needs to be collected.

In forest-thinning scenarios, the emphasis is on the removal of small-diameter material in a cost-effective way. Cost effectiveness of harvest and collection increases as tree diameter at breast height (dbh) increases (Rummer 2002), so costs for these small trees is high. The following costs are calculated with the assumption that all the harvested material is comminuted and no sawtimber, posts, or poles are sold.

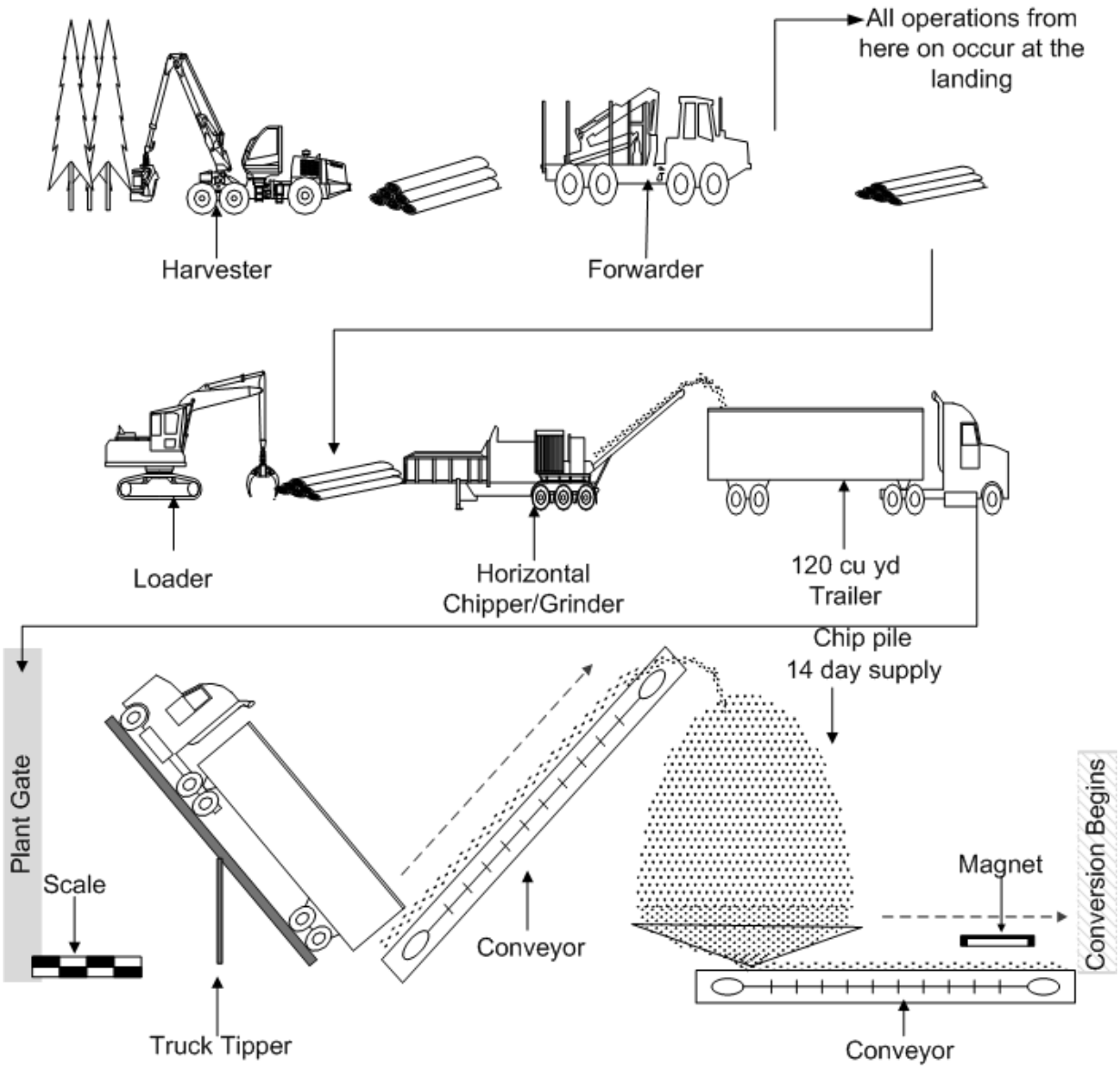

Figure 3. This mechanized fire suppression thinning operation is one of the more cost effective ones reported. Unit operations within the plant gate are the same for all scenarios.

Table 3. Costs from Drews et al. (2000) converted to $/bdt and FoRTS used to calculate loading, grinding and transportation. Note: $2.75 added in the total is the total cost for receiving and storage at the conversion facility. The receiving and storage costs are the same for the three feedstock types (Table 2).

Forest Thinnings Harvest, Collection, and Transportation Costs									
Drews et al. (2000)				FoRTS					
Harvester	Forwarder	Subtotal 2000 $/bdt	Subtotal 2007 $/bdt	loader	chipper	120 cu yd chip van	Subtotal 2005 $/bdt	Subtotal 2007 $/bdt	Total 2007 $/bdt Stump-to-reactor cost
$18.01	$8.31	$26.31	**$31.67**	$1.40	$4.77	$10.25	16.42	**$17.43**	**$31.67+$17.43 = $49.10 + $2.75=$51.85**

Several studies have analyzed productivity and costs associated with a number of different methods of harvesting and collecting forest thinnings (Hartsough et al. 1997; Drews et al. 2000; Rummer 2002). Costs ranged from a low of $49.19 to a high of $151.57/bdt. If the same grinding and transportation assumptions from the FoRTS model that were used for slash are applied to the harvest method used by Drews, a cost of $49.10/bdt is calculated. Adding in $2.75/bdt from table 2 for receiving and storage gives a stump to reactor cost of $51.85. Note that this harvest removed many dead trees, so the percent moisture of the material removed was only 27% (wet basis) on average. This low-moisture content of the material improved the economics of the operation.

Plantation Energy Crops

Short rotation woody crops are often harvested using conventional logging equipment. McDonald and Stokes (1994) conducted a study on a hardwood plantation in Alabama to estimate the productivity and costs of harvesting short rotation sycamore (*Platanus occidentalis L.)* stands with commercially available forestry technologies. To estimate the current cost for harvesting short rotation woody crops with logging equipment, the scenario evaluated by McDonald and Stokes (1994) was updated from 1994 to 2007 costs.

The harvest system consisted of four feller bunchers, two skidders, and a chipper. The system was balanced to efficiently utilize all machines. The 1994 equipment list price given by McDonald and Stokes (1994) was updated to 2007 dollars using the Producer Price Index for machinery (ftp://ftp.bls.gov/pub/time.series/pc/pc.data.19.Machinery). See Appendix A, Table A-4 for costs used in calculating $/bdt.

The cost per hour for each machine was the sum of the capital recovery, ownership costs, insurance, labor, repairs, and fuel. The estimated cost (in 2007 dollars) for each feller buncher, skidder, and chipper was $61.86/hr, $63.48/hr, and $97.67/hr respectively.

Table 4 has the cost breakdown by unit operation and Figure 4 has the assumptions used in the FoRTS model. A 120 cu yd chip van, was used in the plantation wood scenarios because they are widely used and are more mobile at field side. Assuming a moisture content of 45% wet basis,

the felling and skidding (harvest and collection) costs are $10.34/bdt. Loading, grinding, and transportation costs $17.43 (2007 $) for a total of $27.77. The addition of receiving and storage at the plant gate to reactor costs ($2.75/bdt) from table 2 give a-stump-to-reactor cost of $30.52.

Table 4. Unit operations for two energy wood harvest scenarios. Note: $2.75 added in the total is the total cost at the receiving station. That cost for receiving and storage is the same for the three feedstock types (Table 2).

Plantation Energy Wood Harvest and Collection ($/bdt)					FoRTS ($/bdu)				
Source	Feller-buncher	Skidder	Cut and Chip Harvester	Subtotal 2007 $/bdt	Loader	Chipper	120 cu yd Chip Van	Subtotal 2005 $/bdt	Subtotal 2007 $/bdt
(McDonald and Stokes 1994) (Sycamore)	$7.26	$3.08	n/a	**$10.34**	$1.40	$4.77	$10.25	$16.42	**$17.43**
(Buchholtz, Volk et al. 2008) (Willow)	n/a	n/a	$10.50	**(**With Blower-Tractor costs) **$21.00**	n/a	n/a	$10.25	$10.25	**$10.88**
Stump-to-reactor cost (Sycamore)	**$10.34+$17.43+$2.75=$30.52**								
Stump-to-reactor cost (Willow)	**$21.00+$10.88+$2.75=$34.63**								

A cut and chip harvester, based on a New Holland forage harvester with a specialized cutting head, was developed and tested at the State University of New York for harvesting willow (*Salix sp.*). An economic model available online (Buchholtz et al. 2008) estimates the cost to cut and chip willow, transport to the farm edge (see Table 4), and load chips into a forage wagon towed through the filed by a farm tractor. Harvest costs include in-field transportation of wood chips with tractors and forage or dump wagons to the roadside and loading chips into a tractor-trailer using a corn silage blower. The willow model predicts establishment, harvest, collection, comminution, transfer into a chip van and transportation plus receiving and storage will cost $34.63/bdt. This cost is based on a total plantation life span of 22 years

Input and Output

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EcoWillow v.1.0 (Beta)

Input data

General data			CSUNY507
Interest rate	%	6.00%	6.00%
Project size	acre	200	20
Project life	yrs	22	22
Average biomass increment	odt[1]/acre/yr	5	5
Rotation length	yrs	3	4
Land costs (tax, lease) and insurance	$/acre/yr	35	35
Internal administration costs	$/acre/yr	5	5
Acreage incentive payments[2]	$/acre/yr	0	0
Total years of acreage incentive payment[3]	yrs	0	0
Biomass price at plant gate	$/odt	60	60
Stock removal	$/acre	300	300
Startup loans[4]			
Available private capital	$	35,000	35,000
Loan interest rate	%	5.00%	5.00%
Establishment			
Vegetation removal	$/acre	15	15
Contact herbicide	$/acre	30	30
Plow	$/acre	20	20
Disc	$/acre	20	20
Plant cover crop	$/acre	30	30
Kill cover crop	$/acre	30	30
Planting **(calculate in submodel)**	$/acre	924	824
Install fence	$/acre	0	0
Remove fence	$/acre	0	0
Preemergent herbicide	$/acre	45	45
Mech. or chem. weeding first year	$/acre	15	15
Cut back	$/acre	20	20
Mech. or chem. weeding second year	$/acre	15	15
Fertilizer	$/acre	35	35
Total establishment	$/acre	1,199	1,099
Establishment grant	$/acre	0	0
Total establishment incl. grant	$/acre	1,199	1,099
Harvest and transport			
Harvest costs **(calculate in submodel)**	$/odt	10.5	13.9
Transport costs **(calculate in submodel)**	$/odt	11.3	5.5

Output data

Financial analysis tools		Investment time frame 13 yrs[5]	22 yrs
Net Present Value (NPV) realistic	$	-527	-209
NPV optimistic (R+10%; E-10%)[6]	$	630	404
NPV pessimistic (R-10%, E+10%)	$	-1,002	-822
Internal Rate of Return (IRR)	%	-0.9%	4.2%
Production costs, revenues, and earnings			
Average costs per acre	$/acre/yr	285	246
Average (gross) revenue per acre	$/acre/yr	277	286
Average (net) earning per acre	$/acre/yr	-8	40
Average costs per ton	$/odt	62	52
Average (net) earning per ton	$/odt	-2	8
Biomass price at farm gate	$/odt		49
Startup costs[7] (total acreage)	$		267,872
Startup costs per acre	$		1,339
Costs for one commercial harvest	$		31,602
Total interest paid	$		98,055

Yellow cells: insert numbers, insert "0" if not applicable
Grey cells: output from previous inputs
Blue numbers: connection to other sheets

[1]) a subsidy provided on a per acre base ($/acre/yr)
[2]) odt: oven-dried ton; containing 0 % moisture
[3]) Starting with planting year
[4]) Startup loans recieved at year of expense, payback with first earnin
[5]) does not include stock removal costs
[6]) R: Revenues; E: Expenditures
[7]) All costs accumulated until first harvest, grants subtracted

View Planting Submodel | View Harvest Submodel | View Transport Submodel

View Graphs | Back to Welcome Sheet | Print all

Figure 4. Plantation energy wood assumptions From EcoWillow v.1.0 Beta 1

CONCLUSIONS

In the US, there exists a large volume of logging residues (slash) that can be obtained and converted into transportation fuels within the thermochemical or biochemical platforms. Fuel treatment thinnings and short-rotation woody crops (also sometimes called plantation energy wood) can also be utilized for energy. While woody biomass is a widely available bioenergy resource, collecting this material is often not cost-effective. Because woody biomass often has low yields (material per unit area), is found in remote locations (thus, transportation costs can be high), and has low bulk densities, logistics costs are quite variable and can be considerably higher than other bioenergy feedstocks. Nevertheless, advances in technology and supply-system design promise to reduce these costs and make woody biomass a significant feedstock for the cellulosic ethanol and power industries.

This Tech Memo estimates logistics costs of supplying a biorefinery with woody biomass from logging residues ($20.50/bdt), fuel treatment thinnings ($51.85/bdt), and energy woody plantations ($30.52 - $34.63/bdt) using current technologies. The scenarios presented here represent favorable, but reasonable woody biomass supply scenarios. The data quoted in this memo were obtained primarily from peer-reviewed literature and publicly available models. Using this information, INL is working to identify data gaps and plan field studies such as time-and-motion studies, analyzing feedstock rheological properties, and grinding characteristics. Future work will expand these baseline cost estimates to identify potential cost reductions achievable by equipment and supply-chain improvements and to develop feedstock logistics cost targets for future years.

It should be noted that the slash (or residue) system associated with whole-tree logging of merchantable roundwood is considered the current state of technology for woody feedstocks. With this system there is no incremental cost for getting the material into a pile at the landing; the residue is a byproduct of activities that must be carried out to produce the roundwood. Costs for other scenarios are higher because of the extra costs of delivering the biomass to roadside. Slash is sometimes piled by a bulldozer. This may add dirt and other debris that diminishes the slash value. A cleaner collection system may incur an additional cost. The main consideration is that the current costs for collecting and moving slash to the conversion facility is relatively low. It will most likely increase as the demand for slash increases. However, more efficient harvesting operations may lower costs. For example, it may be possible to deliver tops and limbs directly from a dangle-head processor to a small, operator-less chipper or grinder, eliminating most of the soil and other debris while reducing costs by eliminating the loader and operator associated with the grinder.

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Appendix A

Estimating Costs

Table A-1.FoRTS cost assumptions

Machine Costs	Machine/Function Name			
	Knuckleboom *In-woods loading*	Container *1st transport*	Disk *Processing*	120 cy Chip van *2nd transport*
FIXED COST INPUTS				
Purchase price	$181,030		$610,000	$125,000
Scheduled hours/yr	2000		2000	2000
Machine life (yrs)	5		5	8
Salvage value (% of new)	0.20		0.20	0.20
Interest rate (%)	0.10		0.10	0.10
Insurance (Ann Prem.)	$3,600		$12,000	$6,000
Taxes/tags (% of new)	0.00		0.00	0.00
OPERATING COST INPUTS				
Tire cost (total)				$3,500
Tire life (years)				2
Local fuel cost ($/gal)	$1.80		$1.80	$2.00
Local oil cost ($/gal)	$2.00		$2.00	$2.00
Horsepower	174		1000	450
Fuel Consumption (g/hp-hr)	0.022		0.030	6
Oil and lube use (% of fuel)	0.37		0.15	0.1
Repair & Maint (% of dep)	0.90		0.75	0.6
Misc. consumables ($/op hr)			$30.00	
LABOR COST INPUTS				
Basic labor rate	$18	$18	$18	$18
Benefits (% of base)	0.33	0.33	0.33	0.33
Fixed cost ($/SMH)	$22.71	#DIV/0!	$76.47	$13.62
Variable costs ($/PMH)	$25.87	#DIV/0!	$138.75	$19.69
Labor costs ($/SMH)	$23.94	#DIV/0!	$23.94	$23.94

Table A-2. Consumer Price Index conversion factors for 2007 dollars

Consumer Price Index (CPI) Conversion Factors to Convert to 2007 Dollars
Using the CPI-U-RS series, an experimental CPI measure
It can be used when exact comparisons are needed between years during the period starting 1947
as an alternative to CPI-U-X1

To convert dollars of a year to 2007 dollars, divide the dollar amount of that year by the conversion factor (CF) for that year.

For example, $1000 dollars of 1947 = $7936 dollars of 2007 ($1000 / 0.126). Suggest rounding to $7940.

As shown here, it is recommended that numbers be ROUNDED to no more than three decimal places.

Year	CF	Year	CF	Year	CF	Year	CF	Year	CF
1947	0.126	1960	0.167	1973	0.245	1986	0.554	1999	0.804
1948	0.136	1961	0.169	1974	0.270	1987	0.573	2000	0.831
1949	0.134	1962	0.170	1975	0.292	1988	0.594	2001	0.854
1950	0.136	1963	0.173	1976	0.309	1989	0.619	2002	0.868
1951	0.147	1964	0.175	1977	0.328	1990	0.650	2003	0.887
1952	0.149	1965	0.178	1978	0.343	1991	0.674	2004	0.911
1953	0.151	1966	0.183	1979	0.376	1992	0.691	2005	0.942
1954	0.152	1967	0.189	1980	0.417	1993	0.708	2006	0.972
1955	0.151	1968	0.196	1981	0.457	1994	0.723	2007	1.000
1956	0.153	1969	0.205	1982	0.485	1995	0.740		
1957	0.159	1970	0.214	1983	0.505	1996	0.760		
1958	0.163	1971	0.224	1984	0.526	1997	0.776		
1959	0.164	1972	0.231	1985	0.544	1998	0.787		

http://oregonstate.edu/cla/polisci/faculty-research/sahr/cv2007rs.pdf

Table A-3. Cost assumptions (Drews 2000)

Machine	Price ($)	Life (years)	Wages ($/hr)	Total ($/SH)
Harvester	235,000	5	19	114
Forwarder	194,000	5	18	80

Table A-4. McDonald and Stokes 1994 Machine cost assumptions

Assumptions	Purchase Price/List Price	Discount Rate	Labor - Truck	Labor Truck Benefits	Oil ($/gal)
	0.9	0.065	$10.00	0.35	$6.00
	Ins. & fees - feller buncher	Ins. & fees - skidder	Ins. & fees - chipper		Diesel ($/gal)
	$6,801	$7,285	$6,960		$2.88
Producer Price Index (Machinery)	1994	2007			
	129.6	173.4			
Collection Cost	Fixed Costs		Feller Buncher (HydroAx 411)	Skidder (Timberjack 450B)	Chipper (Morbark Model 30)
	List price (1994)		$125,500	$121,000	$289,000
	List price (2007)		$167,914	$161,894	$386,671
	Purchase price		$151,123	$145,704	$348,004
	Lifetime	Hours	10000	10000	10000
	Annual use	Hours	2000	2000	2000
	Productive machine	hours	1300	1200	1500
	Lifetime	Years	5.00	5.00	5.00
	Salvage value	fraction of initial price	0.326	0.326	0.326
	Salvage value	$	$54,696	$52,735	$125,953
	Discounted salvage value	$	$39,922	$38,490	$91,931
	Capital recovery	$/hr	$13.38	$12.90	$30.81
	Other ownership	$/hr	$1.51	$1.46	$3.48
	Insurance and fees	$/hr	$3.40	$3.64	$3.64
	Labor	$/hr	$13.50	$13.50	$13.50
	Total cost	**$/hr**	**$31.79**	**$31.50**	**$51.43**
Variable Operating Costs		Feller buncher (HydroAx 411)	Skidder (Timberjack 450B)	Chipper (Morbark Model 30)	
	Depreciation (straight line)	$22,240.27	$21,442.81	$51,214.65	
Repairs, Lube, Maint., Tires	$/hr	$17.11	$17.87	$34.14	
Fuel	gal/hr	4.5	4.9	4.2	
Fuel	$/hr	$12.96	$14.11	$12.10	
Total	**$/hr**	**$30.07**	**$31.98**	**$46.24**	
	Feller Buncher (HydroAx 411)	Skidder (Timberjack 450B)	Chipper (Morbark Model 30)		
Total Cost ($/hr)	$61.86	$63.48	$97.67		
Productivity (green t/PMH)	15.5	37.5	24.4		
Cost ($/green ton)	$3.99	$1.69	$4.00		
Cost ($/bdt)	**$7.26**	**$3.08**	**$7.26**	**$17.60**	
					Moisture Content (w.b.)
					0.45

Table A-5. EcoWillow model cost assumptions

Harvest Submodel				© 2008 The Research Foundation of State University of New York	EcoWillow v.1.0 (Beta)		
General Input Data			CSUNY507	Equipment			CSUNY507
Acres to be harvested	acres	100	20	No. of harvesters		1	1
Biomass to be harvested	odt/acre	20	20	Transport harvester	$/mi	11	11
Harvester speed	mi/hr	4	4	Transport onfield trsp. units and blower	$/mi	0	0
Double row width	ft	7.5	7.5	Distance	mi	50	50
Average row length	ft	660	660	Total equipment delivery per unit	$	526	
Turning time	min/row	0.75	0.75	Harvester rental	$/hr/unit	180	180
No of rows		880		Harvester fuel consumption	g/hr	16	16
Turning time total	min	660		Harvest unit total costs	$	8,628	
Maintenance time harvester	% of harvest time	17%	17%	Trailer-tractor units		0	3
Harvester speed	hr/acre	0.45		Trailer-tractor rental	$/hr/unit	0	60
Total harvest time	hrs	45		Trailer-tractor fuel consumption	g/hr	0	2.6
				Blower-tractor unit rental	$/hr/unit	0	50
Labor				Fuel price	$/g	0	2.6
No. crews at site		1	1	Maintenance	$/acre		5
Laborer/crew		4	4	On-Site trsp. units and maint. total costs		0	
Foreman/crew (harvester driver)		1	1	Hours at site/unit	hrs	45	
Laborer rate	$/hr	10	10	Total	$	8,628	
Foreman rate	$/hr	20	20	Per acre	$/acre	86	
Hours at site/crew		45					
Indirect labor costs	%	35%	35%	TOTALS			
Total	$	3,646		Labor	$	3646	
Per acre	$/acre	36		Travel	$	40	
				Equipment	$	8,628	
Travel Costs				Total	$	12,313	
No of vehicles		1	1	Total per acre	$/acre	123	
Vehicle costs	$/mi	0.4	0.4	Total per odt	$/odt	6.2	
Distance	mi	50	50				

Total nights		0	0	*Yellow cells: insert numbers, insert "0" if not applicable*			
Hotel costs	$/night/person	0	0	*Grey cells: output from previous inputs*			
Meal costs	$/night/person	0	0	*Blue numbers: connection to other sheets*			
Total crew travel costs	$	40		*Bold & blue: link to input-output sheet*			

Appendix B

Acronyms

FoRTS	Forest Residues Trucking Simulator
INL	Idaho National Laboratory
SRWC	short-rotation woody crops
Bdt	Bone dry ton
Bdu	Bone dry unit
Odt	Oven dry ton